INTERNATIONAL TELECOMMUNICATION UNION
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EPFD LEVELS THAT CAN CAUSE SYNC LOSS OF Ku-BAND FSS GSO SATELLITE NETWORKS

Modify section 3 of the CPM Report to reflect the conclusions of the attached Annex.

Proposed text changes for the draft CPM Report are shown in CPM99-2/89 and below.

MOD **3.1.2.1.2 c)**

Please add the following text to the end of section c):

The EPFD levels to protect the GSO network against sync loss in most rain zones are given in the following table. These levels represent a compromise burden that is placed on the GSO operators when protecting for sync loss.

Antenna diameter (m)	Sync loss threshold (dBW/m^2/40 kHz)
3.0	-163
4.5	-165
6.0	-166
10.0	-169.5

Reasons: Section 3.1.2.1.2 of the draft CPM Report gives a table of sync loss thresholds for specific coding rates, but does not quantify the EPFD levels that will cause a GSO sync loss event due to non-GSO interference.

MOD **3.1.2.3.2 b)**

For those individual links which ~~might~~ are not ~~be~~ fully protected by the $EPFD_{down}$ masks, various ways of compensating for any shortfall in protection were considered and it was concluded that the most convenient one would usually be an increase in the satellite e.i.r.p. allocated to the GSO link, where feasible. Most of the links in the CR92/CR116 database which the $EPFD_{down}$ masks do not protect according to the 10% criterion are characterized by large earth station antennas and small margins~~, and hence their satellite e.i.r.p.s. are relatively low compared with other links of similar bit rates~~. Therefore the reduction in transponder capacity caused by such e.i.r.p. increases, though representing a burden, could be modest in multicarrier transponder cases. It is noted that it is appropriate for some links to be designed to have small margins. Furthermore, it should be noted that GSO commercial users who implement transponders, lease them on the basis of power and bandwidth. Therefore, it is typical to maximize the utilization of the resource where there would be little additional power available in the transponders to protect against non-GSO interference.

For earth station antennas between 3 and 10 m, depending on coding and link availability, synchronization loss can occur in almost any rain zone due to the non-GSO interference levels represented by EPFD masks (curve A and B). Analyses have shown that many of the links in the CR92/CR116 database will suffer from a large number (several hundred) of synchronization losses per year. The only way to compensate for the sync loss shortfall is by increasing the e.i.r.p allocated to the GSO link, where feasible.

Reasons: To take into account commercial GSO usage of transponders and point out that synchronization loss can occur in almost any rain zone depending on link characteristics. Also see paper CPM99-2/135.

Justification

1 Introduction and background

WRC-97 adopted provisional EPFD limits for the purpose of protecting GSO systems from non-GSO systems in the same band. JTG 4-9-11 was tasked to review the provisional pfd limits, but failed to sufficiently address the problem of GSO sync loss as a consequence of non-GSO interference.

Several Administrations (United States, France and United Kingdom) and INTELSAT have provided inputs to ITU-R WP 4A addressing the subject of GSO sync loss as a consequence of non-GSO interference. In general all inputs have reached similar agreement on the interference levels that would cause sync loss problems. All of the documents agreed that the EPFD limits being considered by the JTG to protect GSO networks would not protect from sync loss for all situations. No final conclusions have yet been reached on this issue.

In many applications, sync loss leads to outages longer than the interference event, which can greatly impact GSO network performance. This paper reviews the JTG, WP 4A and more recent studies on sync loss that lead to the conclusion that sync loss protection is an important issue yet to be resolved.

2 Review of previous work

ITU-R Document WP 4A/371 (INTELSAT) presented and analysed EPFD levels that would cause sync loss to the link budgets that they provided to ITU per Resolutions CR92 and CR116. The document concludes that, if the current levels of downlink EPFD limits for 100% of the time contained in Article S.22 of the Radio Regulations for non-GSO systems are maintained, in particular for Ku-band, synchronization events will contribute significantly to degrade the performance of GSO digital transmissions beyond the target values specified in Recommendation ITU-R S.1323.

The range of sync loss deficits, in the presence of a -170 dBW/m^2/4 kHz 100% EPFD level, for the links considered are shown in Table 1.

TABLE 1

WP 4A/371 sync loss deficits

Antenna diameter (m)	Minimum deficit (dB)	Maximum deficit (dB)
10	6.4	11.5
8	0.8	9.5
2.4	0.1	1.7

ITU-R Document WP 4A/276 (France) analysed the sensitivity, relative to a -170 dBW/m^2/4 kHz 100% EPFD level, of all the CR92/CR116 links to synchronization loss. In the conclusions they ignored certain INTELSAT 8-PSK and United States links. The findings are summarized below:

- 21% of the CR92 and 30% (ignoring INTELSAT and United States links) of the CR116 links were susceptible to sync loss.
- No antenna < 1.2 m had a sync loss deficit > 1 dB
- No antenna < 3 m had a sync loss deficit > 3 dB
- No antenna < 6 m had a sync loss deficit > 5 dB
- No link had a sync loss deficit > 11 dB

It is observed that even without the discarded links, the results are consistent with the INTELSAT and United States studies (described below). The reason given, in Document WP 4A/276, for ignoring the selected United States links was that "in the case of multicarrier operation, the calculations are based on transponders which are not shared by several types of receive earth stations, and are independently optimized to suit only one type of station". We understand this to mean that it was assumed that, for the ignored sensitive links, in order to close the links properly, the satellite transponders serving those links were assumed to operate in an abnormal and therefore unrealistic manner. It is argued that this statement is incorrect. In the case of multicarrier operation the analysis was based upon transponder settings that were typical and accommodating a range of earth station sizes.

Document WP 4A/276 concludes that the sync loss problem is minimal. "For all the links susceptible to synchronization loss, the actual occurrence of this situation would be only in very small portions of the Earth's surface (typically less than 1%) for any given GSO satellite location, as shown in Document JTG 4-9-11/268. "It is noted that subsequent studies by both France and the United States have not verified the "less than 1%" figure. Later United States studies using a supplied non-GSO satellite antenna Bessel function [4A/350] side-lobe pattern, show that high levels of interference can occur over a substantial portion of the Earth's surface. That improvement is not at all sufficient to protect sensitive 3-10 metre earth stations from non-GSO EPFD levels. These results are discussed in detail in a companion paper [USCPM44].

ITU-R Document WP 4A/319 (United Kingdom) attempts to find a compromise maximum EPFD level for sync loss. The proposed level is -173 dBW/m^2/4 kHz. The document also concludes that this level would adequately protect all but 35 of the 568 "Annex 2" Ku-band links in the database. Assuming that the GSO links increased their e.i.r.p.s by 1 dB (a reasonable burden sharing according to the article) the number of exceptions could be reduced to 23 unprotected links. The document concludes that since the 23 links are a "small" proportion of the 568 "sensitive" links the "exceptions would form a very small proportion of the total number of existing and planned Ku-band links".

However, in subsequent ITU-R JTG meetings there was disagreement on the meaning of the 23 links that could not be protected by this new proposed 100% level. In this regard ITU-R Document 4-9-11/TEMP/104 states that: "It was agreed that it is not possible to determine the proportion of sensitive links in the environment based on the information contained in the CR92/CR116 database. A single link in the database may be representative of hundreds or even thousands of links in the environment".

ITU-R Document WP 4A/329 (United States) analysed the sensitivity, relative to a -170 dBW/m^2/4 KHz 100% EPFD level, of United States CR116 links from one GSO operator to synchronization loss. The results of this study are shown in Table 2. These levels are similar to those levels found in the other documents, including 4A/276 (France) which ignored these United States links.

TABLE 2

Mean and standard deviation of the sync loss deficit for United States CR116 links

Antenna size (m)	Mean sync loss deficit (dB)	Std Dev
1.8	-1	1.6
3	2	1.7
7	7	3
10	8	3

With regard to the ignored United States links in Document WP 4A/276, it has been argued in this document that those links were ultra sensitive and therefore unrepresentative of actual existing links. Reply arguments indicated that what makes those United States and similar links sensitive, is the earth station location, and an efficiently designed margin requirement that adequately attains desired link availability with sufficient margins.

The earth station location identifies the rain environment it must operate within. Rain is the primary impediment to service availability. Additional power (margin) is required to compensate for the rain attenuation and during clear sky that margin can mask other sources of interference. Therefore, areas of the world that expect heavier rain are less sensitive to interference since they require larger power margins, while areas that expect lighter rain are more sensitive to non-GSO interference. Figure 1 shows an ITU rain zone map of the world. It is noted that more than 50% of the United States land area are in very low rain zones (rain zone E or lower).

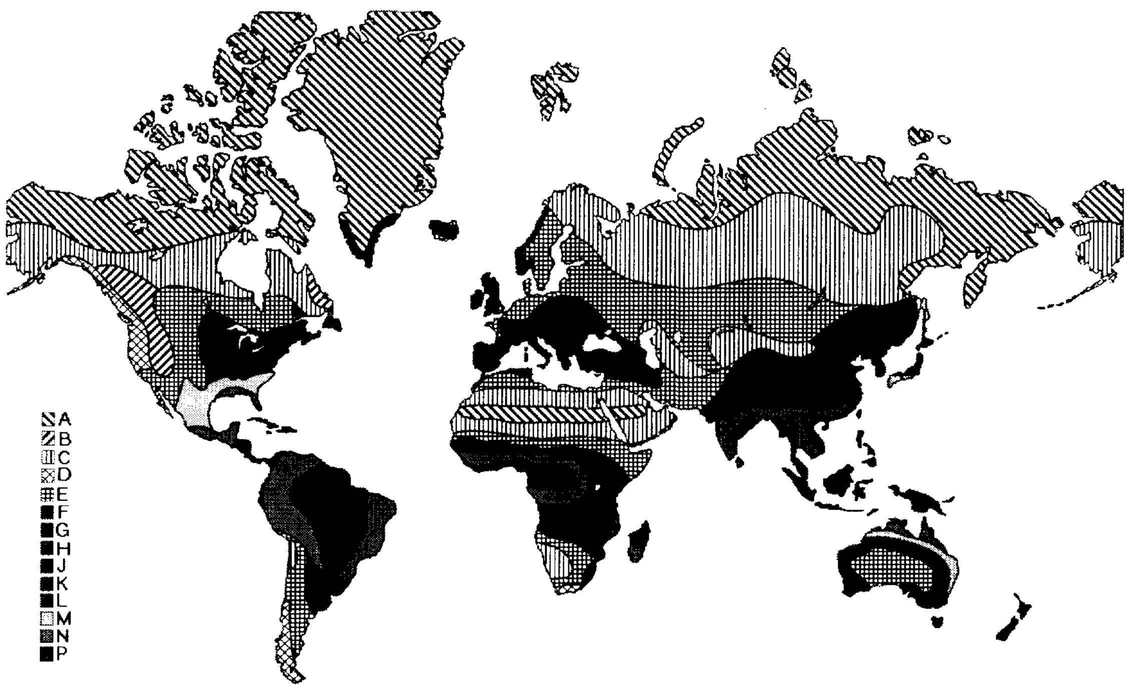


FIGURE 1

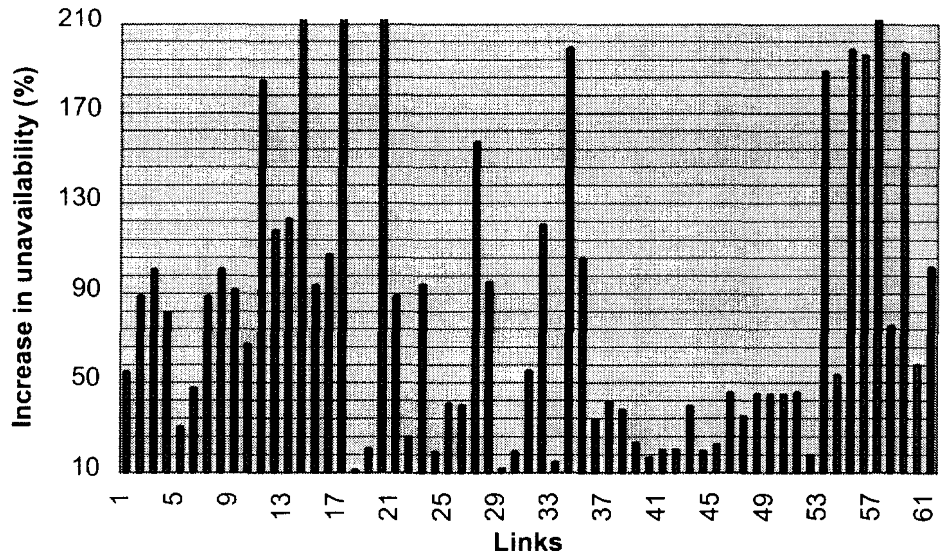
ITU rain zone map

As a matter of economic necessity (cost), users of commercial satellite networks will generally closely budget power margins that compensate for rain, pointing errors, aging losses, and increases in system noise temperature due to other interfering sources. Most commercial links are designed to achieve acceptable service at the lowest link transmission power possible thus in a low rain zone the links will be more susceptible to loss of synchronization because of non-GSO interference.

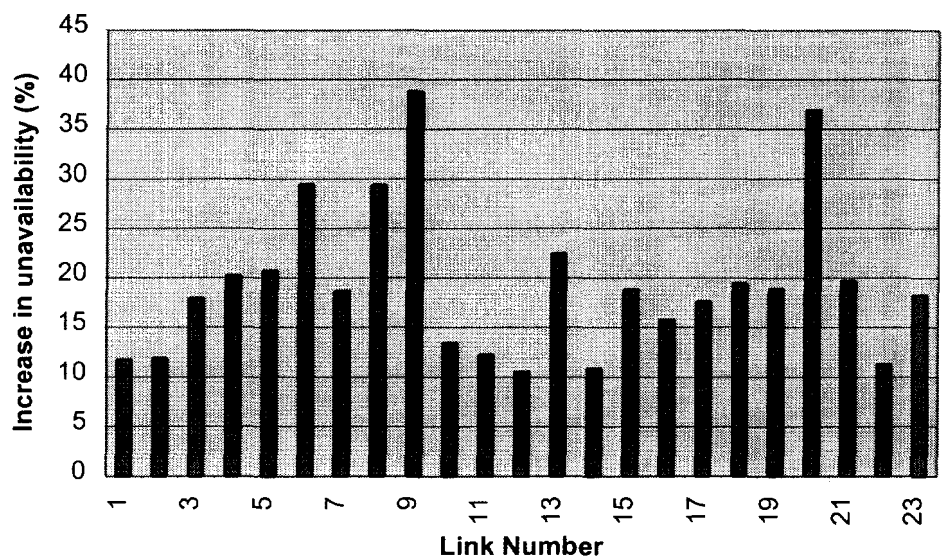
3 Newly considered links

This section provides additional link information that was provided to the United States Administration regulatory agency (Federal Communications Commission) at their request. The information is taken from a proprietary database of about 200 links used by one commercial user. The links are distributed over the entire United States. An analysis of that database indicates that the link margins are just sufficient to meet a desired level of availability (99.9%). The links include earth stations with antenna diameters of 2.4 m, 3.8 m, and 4.5 m.

The link budgets are implemented with sufficient additional power margin needed for the rain zones where located. A complete analysis of the links indicates that when using EPFD curve A, 29% of the links fail the 10% criteria in Recommendation ITU-R S.1323 and with curve B, 11% fail the 10% criteria. Figure 2 shows the increase in unavailability for the links failing the 10% criteria using EPFD curves A and B. The largest sync loss deficit was 2.7 dB for a 3.8 m link. This result is consistent with the findings described in Document WP 4A/329 (United States).



a) Results using curve A



b) Results using curve B

FIGURE 2

Increase in unavailability for links failing the 10% criteria

4 Generic approach

Consistent with the above studies a parametric study of link budgets in various rain zones and with various system temperatures was performed to investigate the range of EPFD values that are needed to protect against sync loss. The results of this study are shown in Annex 1.

The analysis was performed on earth stations with antennas larger than or equal to 3 m that are susceptible to sync loss. These larger antennas are often used for distribution at high data rates and for providing gateway services where network data is concentrated. Links using these antennas typically operate with availabilities between 99.9% and 99.99%. The higher availability (99.99%) is easily achieved in low rain zones (ITU-R A to E) and is often required for critical applications in all rain zones.

Annex 1 demonstrates that non-GSO interference allowed by EPFD masks (curves A and B) can cause synchronization loss in GSO FSS links. For earth station antennas between 3 and 10 m, depending on coding and link availability, synchronization loss can occur in almost any rain zone due to the non-GSO interference.

From the Annex 1 study, Table 3 shows the EPFD levels that will protect most GSO FSS links from sync loss in rain zone B. It is noted that rain zone B covers approximately 13% of the United States and has a significant population. The values in the table were calculated for a link with 1/2 rate coding and an availability of 99.99%. System temperatures are representative of what is realizable in practice.

TABLE 3

EPFD levels required to protect against sync loss

Antenna diameter (m)	System temperature (K)	Sync loss threshold ($dBW/m^2/40$ kHz)
3.0	350	-163
4.5	450	-165
6.0	600	-166
10.0	800	-169.5

5 Conclusion

The values in Table 3 are comparable to the results found analysing the CR92/CR116 links. It has been demonstrated that sensitive links needing the levels of protection shown in Table 3 do occur in practice in low rain zones.

ANNEX 1

Sensitivity of Ku-band FSS GSO satellite networks to synchronization loss and timing recovery from non-GSO EPFD interference levels

A1 Theoretical sync loss EPFD calculation

A simple I/N calculation can be performed to demonstrate whether or not a GSO earth station in a given rain zone is susceptible to EPFD induced sync loss. The calculation depends on the received carrier-to-noise ratio $(C/N)_{sync\ loss} = C/(N+I)$ at which sync loss occurs. $(C/N)_{sync\ loss}$ is typically in the range of 1 to about 4 dB below $(C/N)_{required}$ needed for the minimum BER performance objective desired for the link. A link where $\Delta(C/N)$ $((C/N)_{required} - (C/N)_{sync\ loss}) = 1$ dB is representative of 1/2 rate coding while $\Delta(C/N) = 3$ dB is representative of 3/4 rate coding.

Table A-1 reproduces modulation and sync loss information for systems with data rates less than 34 Mbits/s presented in section 3.1.2.1.2.3 of the JTG 4-9-11 proposed CPM text.

TABLE A-1

Modulation and coding	C/(N+I) (dB)
QPSK rate 7/8	6.0
QPSK rate 3/4	5.3
QPSK rate 1/2	3.5
8-PSK	8.1
16-QAM	11.0

Section 3.1.2.1.2.3 of the JTG CPM text provides information on the conditions leading to loss of synchronization for various digital modulations, however it does not recommend EPFD limits that result in sync loss.

Since the amount of carrier-to-noise degradation to cause sync loss is known (for a given link) and, the amount of rain margin needed to protect a network in a given rain zone for a specific frequency can be estimated (see for example Table A-2), that information can be used to calculate the harmful interference levels that will cause loss of sync lock for GSO links during the inline condition (i.e. GSO earth station, non-GSO satellite and GSO satellite are in line.

TABLE A-2

Representative rain zone power compensation margins for the12 GHz band

Link avail.	**Rain zone**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**J**	**K**	**L**	**M**
99.9%	Rain	0.6	1	1.3	1.7	2	2.5	2.7	2.9	3.2	3.9	5.4	5.6
99.99%	Margin (dB)	1.6	2.6	3.3	4.3	5.1	6.6	7.1	7.6	8.4	10.1	14	14.6
Rain margin calculated per ITU-R PN.618-5 for 99.9% and 99.99% availability. Assuming altitude of all ESs are at 0.25 metres, with vertical polarization at a latitude of 40 degrees and an elevation angle of 20 degrees.													

The performance degradation of a communications link can be expressed in terms of an equivalent increase in the system noise temperature as compared to a link without the degrading influence. That relationship can be expressed as:

Degradation (dB) = $\mathbf{10Log((T+\Delta T_I)/T)}$

It can also be shown that under clear sky conditions, sync loss will occur when:

Degradation (dB) = $\mathbf{M_R\ (dB) + \Delta(C/N)(dB)}$

where:

T	=	system noise temperature (°Kelvin, include noise from all known sources),
ΔT_I	=	system noise temperature increase due to added interference source (°Kelvin),
M_R	=	rain margin (dB),
$\Delta(C/N)$	=	dB decrease in threshold C/N from the lowest performance objective to the sync loss level.

Accordingly then, under clear sky conditions, the relationship between the normal operating system noise temperature, the additional rain margin and the noise temperature increase due to interference which might cause sync loss is given by equation (A.1) as follows:

$$\mathbf{10Log((T+\Delta T_I)/T) = M_R\ (dB) + \Delta(C/N)(dB)} \qquad \text{(A.1)}$$

The level of received interference power that would cause sync loss can be determined by solving for ΔT_I in equation (A.1).That resulting interference level allows the determination of the EPFD level that would cause sync loss to occur. Accordingly, the noise temperature increase due to non-GSO interference that would cause sync lock is given in equation (A.2) as follows:

$$\mathbf{\Delta T_I = (10^{(M_R+\Delta(C/N))/10}-1)T\ (°Kelvin)} \qquad \text{(A.2)}$$

The increase in noise temperature ($\mathbf{\Delta T_I}$) due to non-GSO interference can then be used to calculate the resulting increase in received interference power ($\mathbf{I_T}$ **(dB))** with equation (A.3) as follows:

$$\mathbf{I_T\ (dB) = 10Log\ (K\Delta T_I B)\ (dBW)} \qquad \text{(A.3)}$$

where:

B	=	transmission bandwidth (Hz),
10 LogK	=	10 Log(Boltzman's constant) = -228.6 dB,

The EPFD of receive non-GSO interfering signal I_T that will break sync lock can be determined from equation (A.3) by subtracting the equivalent antenna area as shown in following equation (A.4):

$$\mathbf{Epfd_{sync\ loss} = I_T + 10Log(\eta\pi D^2/4)} \qquad (A.4)$$

where:

D = earth station antenna diameter

η = antenna efficiency

For example Figures A-1 to A-4 show EPFD levels that will cause loss of synchronization in GSO FSS links. Table A-3 shows the earth station sizes and system temperatures assumed in this analysis. The temperatures are realizable in practice.

TABLE A-3

Earth station sizes and system temperatures

Earth station antenna diameter (m)	System temperature (K)
3	350
4.5	450
6	600
10	800

A2 Conclusions

It would appear from the above study that the ITU-R 1323 criteria of limiting non-GSO interference to 10% additional unavailability which the ITU JTG 4-9-11 based its studies upon, does not adequately address the subject of loss of sync lock. This is reflected in the minimal consideration on the subject of synchronization in the proposed JTG 4-9-11 CPM text (see section 3.1.2.1.2.3).

Loss of synchronization can be extremely disruptive to certain services that, under current circumstances, are adequately provided over satellite networks. Accordingly then, care must be taken in defining and limiting the interference environment for the GSO FSS in order to guarantee widest application of use of the GSO FSS. That definition should include criteria that takes into account the effects of sync loss as well as unavailability. This might consist of specific values for excess duration, frequency of the excess and the maximum number of sync loss causing excess events.

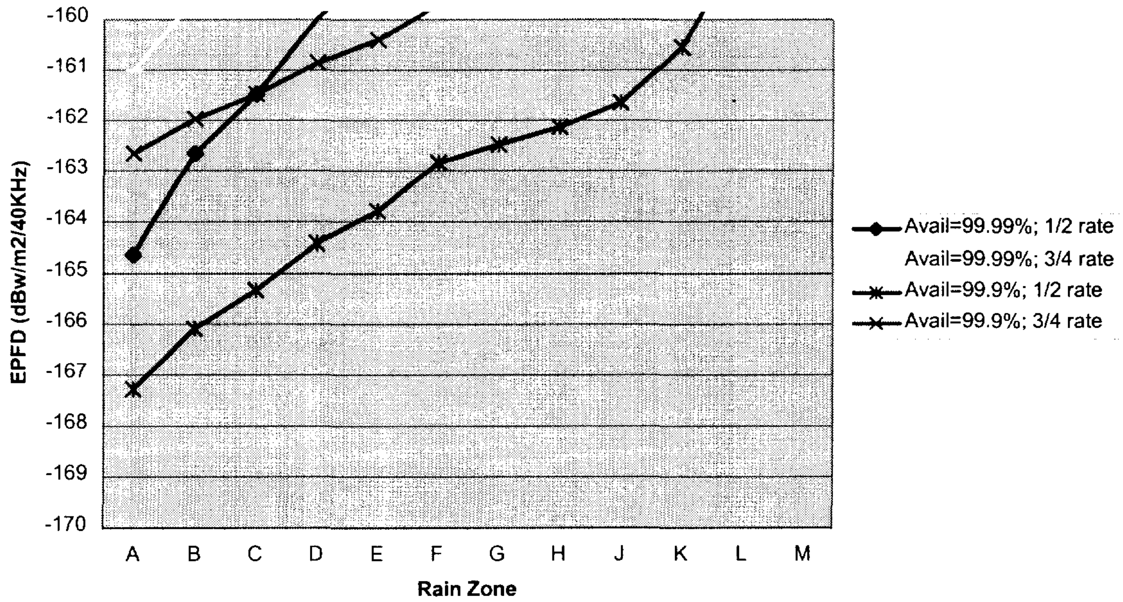


FIGURE A-1

3 m earth station pfd levels causing sync loss

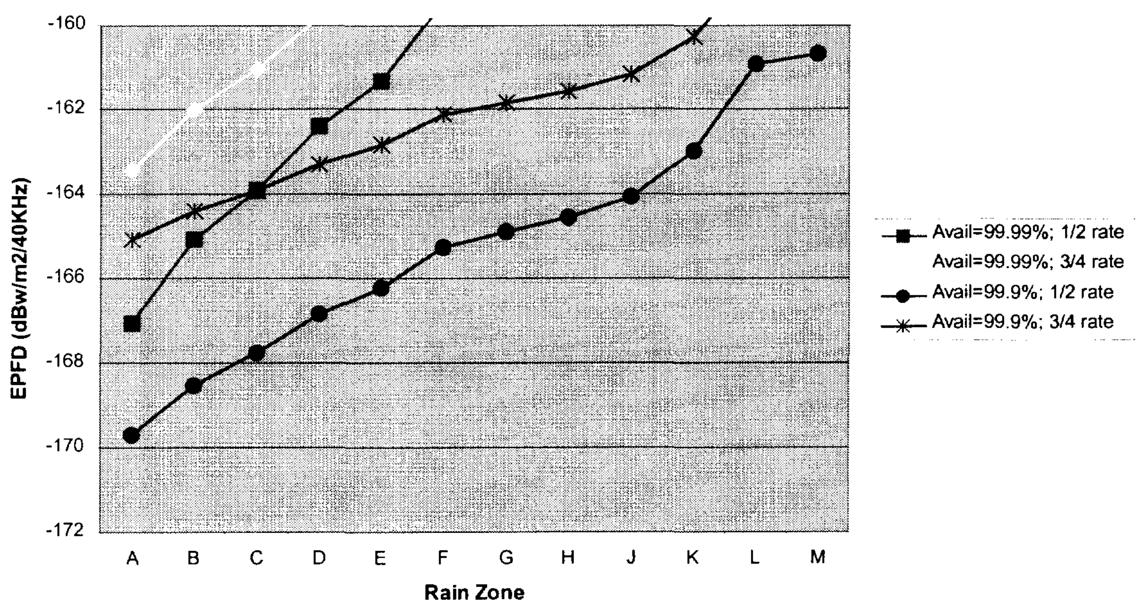


FIGURE A-2

4.5 m earth station pfd levels causing sync loss

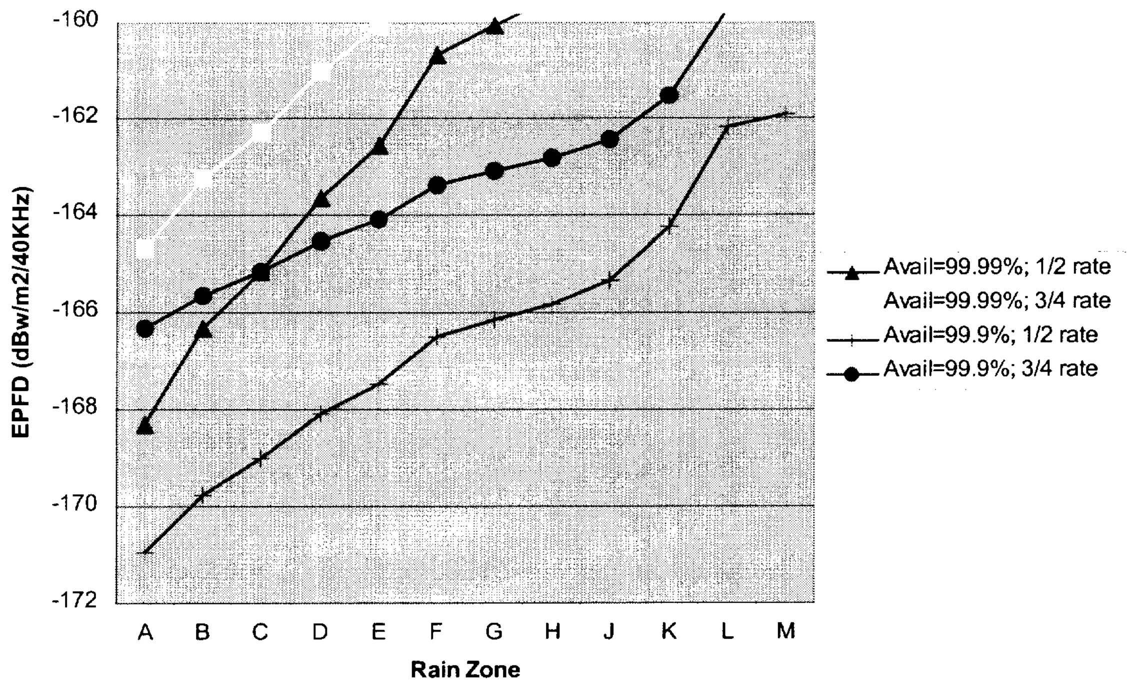


FIGURE A-3

6.0 m earth station pfd levels causing sync loss

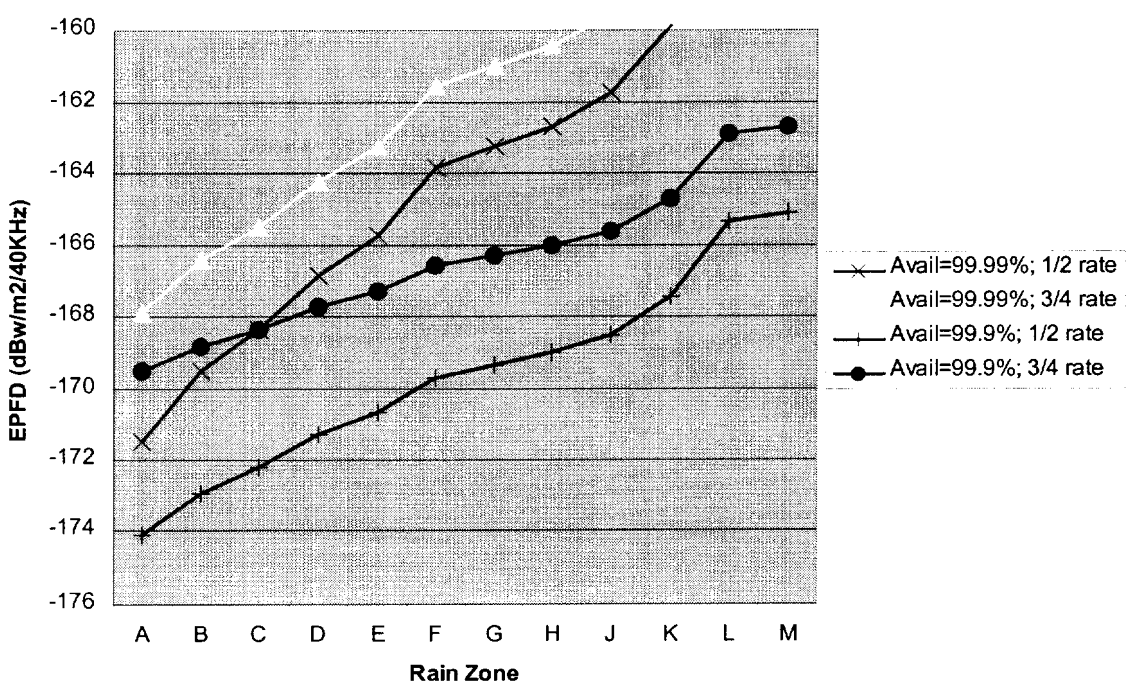


FIGURE A-4

10.0 m earth station pfd levels causing sync loss

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PROPOSED CHANGES TO SECTION 3.1.2.3.2 b) OF THE CPM TEXT BASED ON ANALYSIS OF THE GEOMETRIC DISTRIBUTION OF NON-GSO INTERFERENCE

Recommended modification to the CPM text section 3.1.2.3.2 b)

The following changes to draft CPM text are recommended based on the analysis described in Annex 1 (also see changes to this section in CPM99-2/137 and CPM99-2/134).

The introduction of power limits into Article **S22**, to share frequencies with non-GSO FSS systems, represents the acceptance of a burden on the part of the GSO FSS networks: i.e. the establishment now of acceptable interference levels from non-GSO FSS systems into all present and future GSO FSS networks, and the quantification of the protection provided for GSO FSS under No. **S22.2** in the relevant bands.

~~The calculation of the impact of a given EPFD$_{down}$ mask on each link in the CR92/CR116 database has necessarily been based on a combination of significantly conservative assumptions which, for an individual link, has a low probabiity of occurring~~. ~~Also, i~~In order to ensure protection, a number of worst-case circumstances have been assumed in drawing up the specification for the BR compliance verification software.

Taking into account the fact that ~~conservative~~ assumptions have had to be taken, attention is drawn to the following factors:

- The ITU-R analyses were conducted with the aim of protecting as many of the CR92/CR116 links as possible.
- The EPFD$_{down}$ limits must be met for every location on the Earth's surface and for any pointing direction towards the GSO. ~~However, any given non-GSO FSS constellation will generate its maximum EPFD$_{down}$ level in only a modest proportion of the Earth's surface.~~Due to station keeping errors, some non-GSO FSS constellations can generate their maximum EPFD$_{down}$ levels over a large proportion of the Earth's surface. For each earth station location the maximum interference peaks will be relatively infrequent. ~~Nevertheless~~Also, EPFD$_{down}$ levels below the maximum may be a problem for some GSO links. Quantification of these factors depends heavily on the characteristics of the non-GSO FSS system.

- ITU-R antenna reference patterns, including the pattern in draft new Recommendation ITU-R S.[Doc. 4/57], are employed for GSO earth stations, in both the ITU-R analyses and the BR software specification. These reference patterns necessarily err on the side of caution, and in practice the roll-off of the GSO earth station antenna main beam is likely to be rather faster than modelled. Also, in the models of non-GSO satellite antennas used in the analyses, the side-lobe gain assumed is likely to be somewhat higher than reality. These factors lead to conservative estimates of the duration and levels of interference peaks.
- The methodologies used to derive EPFD masks lead to conservative results because the only sources of short-term degradation taken into account are rain fading and non-GSO interference. It is noted that the rain fade models used are long-term averages, and that the rain attenuation varies substantially from year to year.

Reasons: The analysis presented in Annex 1 demonstrates that maximum EPFD levels can be present over a large percentage of the Earth's surface.

ANNEX 1

1 Introduction

Document 4A/353 argues that F-SAT-MULTI 1B will cause maximum EPFD levels on a small portion of the Earth's surface. We have been informed by F-SAT-MULTI 1B engineers that the analysis assumed the constellation configuration will effectively repeat every 10 hours and 41 minutes. This is an assumption of perfect tracking, and if not true could significantly underestimate the actual proportion of the Earth's surface that will be affected. We have also been informed by the same source that the 10 hour 41 minute repeat cycle will have a topocentric error between 0.3° and 0.5°.

This document analyses the percentage of the Earth's surface affected by short-term interference from F-SAT-MULTI 1B taking into account such small errors in the non-GSO repeat cycle.

2 Analysis

For some non-GSO systems, the short-term interference from their satellites to the GSO ground stations occur when the non-GSO spacecraft passes through the GSO ground station antenna main beam. For this to occur, the ground stations receiving this short-term interference must all be in the vicinity of "in-line" locations on the Earth. These in-line locations can be predicted by projecting a line from the GSO through the non-GSO onto the ground as shown in Figure 1. Since the GSO ground station points at the GSO, the non-GSO will be directly in the antenna main beam.

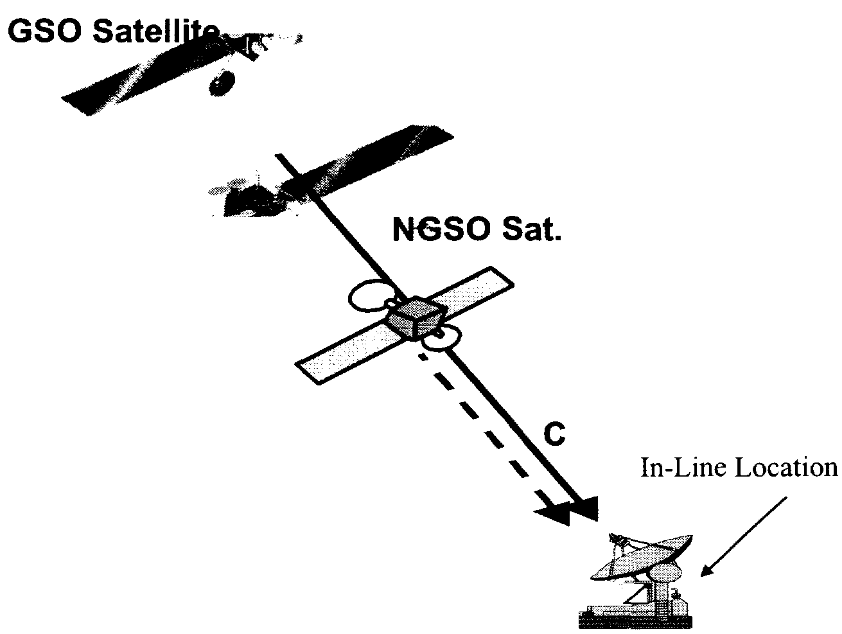

FIGURE 1

In-line non-GSO interference

For any non-GSO spacecraft position, there will be a corresponding region overlapping the in-line location that will receive high levels of EPFD interference. The width of the region depends on the GSO ground station antenna size. The larger the antenna's dish size, the smaller the region. As the non-GSO spacecraft orbits the Earth, these regions follow the spacecraft. This is why Document 4A/353 shows a cross-hatch pattern on the ground of high EPFD levels as shown in Figure 2. Each line on the graph corresponds to a non-GSO spacecraft passing overhead.

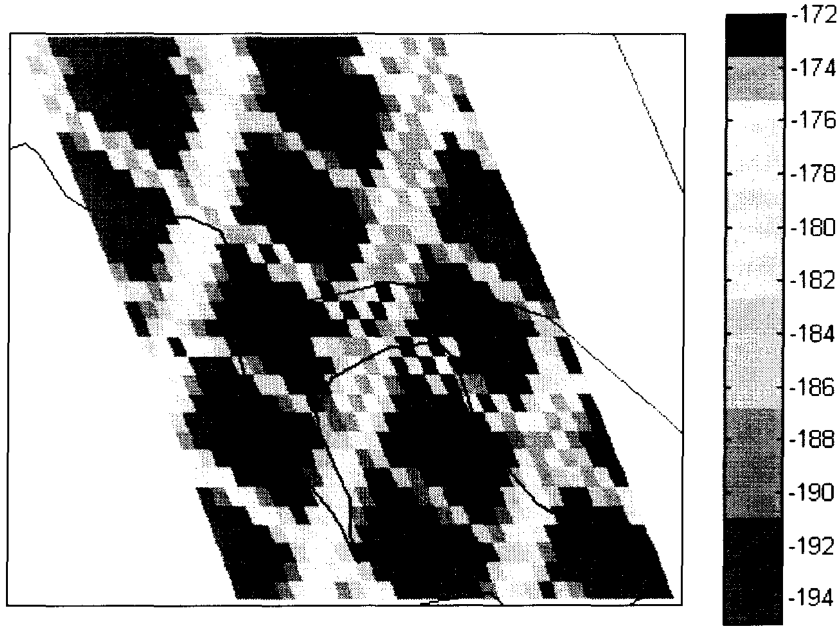

FIGURE 2

From Document 4A/353: Maximum EPFD into a 10 metre antenna (900 sub-cells of 0.1° x 0.1°, two "black" sub-cells between -172 and -173 dBW/m²/4 kHz)

If the non-GSO has a short repeat cycle, then only a limited number of these interference lines appear on the ground. The F-SAT-MULTI-1B constellation repeats every 10 hours and 41 minutes. With this perfect repeat cycle only a small percentage of the Earth's surface will see these in-line EPFD levels for GSO ground stations with large dish antennas. However, non-GSO satellites will not perfectly repeat their orbits. There are always some station keeping errors.

Figure 3 shows a close up of F-SAT-MULTI-1B maximum EPFD levels (for a 10 metre GSO ground antenna) between 49° and 50° latitude and between 25° and 26° longitude. Notice with perfect station keeping the criss-cross pattern is clear. However, for a non-GSO with a topocentric error of 0.5°, virtually all locations on the graph could receive high interference levels.

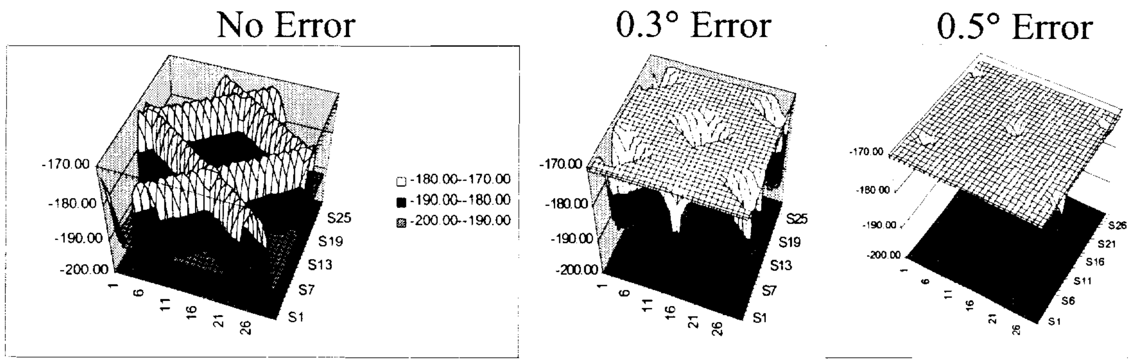

FIGURE 3

The maximum EPFD levels (10 metre) for locations on the ground between 49 and 50 degrees latitude and -25 and -26 degrees longitude for various topocentric angular errors for the non-GSO repeat cycle

Figure 4 shows the percentage of the Earth's surface that will be affected by "in-line" interference. The analysis simulated 10 000 random locations on the Earth's surface with a corresponding 10 000 random GSO locations. From these locations, the percentage of the Earth's surface that could be affected by in-line interference within 0.5 dB of discrimination from the GSO antenna is computed.

The percentage of the Earth's surface affected assuming a perfect repeat cycle is only 6.6%, while assuming a 0.5 degree topocentric angular error, the percentage of the Earth's surface affected increases to 67%.

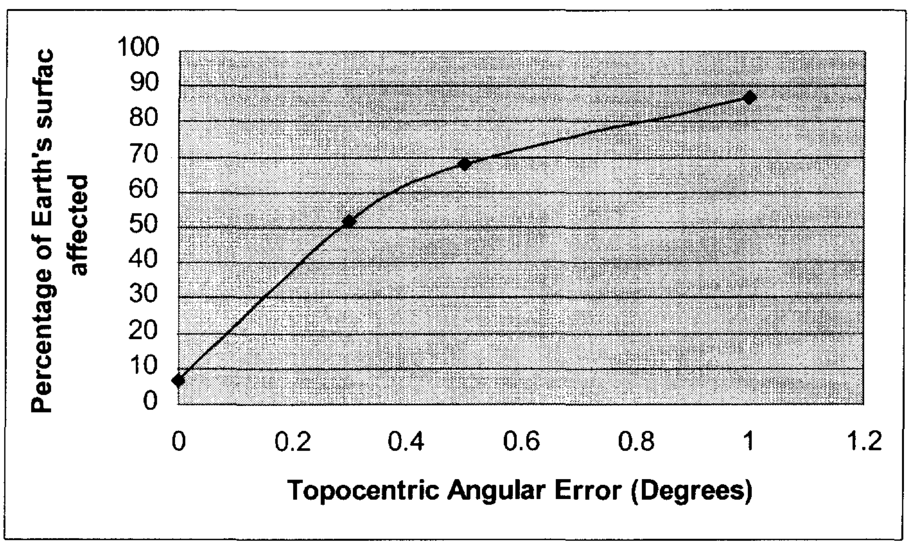

FIGURE 4

Percentage of Earth's surface affected by in-line interference within 0.5 dB of GSO on axis gain

Not all in-line locations on the Earth will receive maximum EPFD levels due to variations in the non-GSO side lobe levels. Figure 5 shows a plot of F-SAT-MULTI 1Bs in-line EPFD levels the Earth's surface. The analysis assumed a GSO at 0 degrees latitude and 0 degrees longitude. Notice a large percentage of the Earth's surface will receive EPFD levels in excess of -162 dBW of interference.

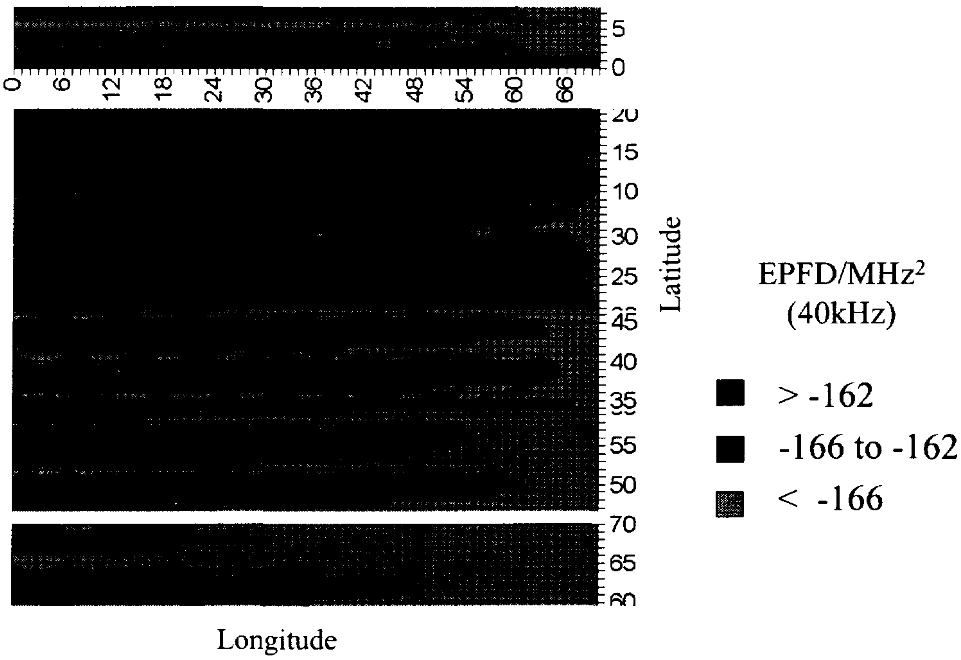

FIGURE 5

In-line maximum EPFD levels

4 Conclusion

The percentage of the Earth's surface affected by in-line interference is highly dependent on the non-GSO station keeping error. It is noted that an increase in topocentric error will lead to a decrease in the probability of the occurrence of an in-line event at the worst-case location. Assuming a station keeping topocentric error of 0.3 degrees, 51.9% of the Earth's surface will experience in-line interference from the F-SAT-MULTI 1B. Since F-SAT-MULTI 1B is expected to have a topocentric angular error between 0.3 and 0.5 degrees, the majority of the Earth's surface will experience in-line interference.

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A criterion for the allowable incremental increase in the number of sync loss events due to NGSO interference

Proposed text changes for the Draft CPM Report are shown in US CPM/66.

Reasons: *Section 3.1.2.1.2 of the draft CPM report gives a table of sync loss thresholds for specific coding rates, but does not quantify how often GSO sync loss events may be increased by NGSO systems. This paper sets a threshold for sync loss events that currently occur in GSO systems due to rain and allows NGSO systems to increase the number of sync loss events an additional 10%.*

ANNEX

Introduction

WRC-97 adopted provisional pfd limits for the purpose of protecting GSO systems from NGSO systems in the same band. The ITU-R JTG 4-9-11 was tasked to review the provisional PFD limits, but failed to sufficiently address the problem of sync loss. ITU-R S.1323 recommends 3.2 says that NGSO interference "not lead to loss of synchronization in the desired network more than once per x days." The value of x was left for further study.

The loss of synchronization (Sync loss) can to service outages longer than the interference event and can greatly impact performance. This paper estimates the number of sync loss events that GSO networks suffer per year from rain events and proposes a value for x for recommends 3.2 of ITU-R S.1323 to reflect the additional sync events caused by NGSO interference

Sync Loss Effects on Satellite Networks

Many FSS services are of a digital nature employing sequentially layered and synchronized coding schemes that address security, digital compression, and error correction and service applications. High levels of interference from NGSO systems, presumably corresponding to time allowance for unavailability, or even shorter periods of time could potentially result in the loss of synchronization of GSO communications which may in turn cause extended periods of service outage.

It has been reported that synchronization recovery times can take between 1 to 40 seconds depending on the network application, data rate and coding [4A/276]. Additionally, sync loss may have much greater impacts on higher network layer protocols such as those used to carry internet traffic. Satellite carriage of Internet data traffic is now a significant percentage of both long haul and Direct-to-Home services. The major portion of this traffic uses the Web-based Internet Transmission Control Protocol (TCP) initially developed for terrestrial links. TCP is an end-to-end protocol for delivery of errorless data relying on data re-transmission to achieve such performance on links that can experience traffic interruptions.

The sensitivity of the Internet TCP protocol to transmission interruptions is demonstrated by the following example. Assume an Internet session in which the packet lengths can vary between 2 and 16 Kbytes. As long as there are no errors, the transmission will use 16 Kbyte packets. Interruptions due to sync loss, however, may cause TCP to revert to congestion control and operate in the slow start mode. Under this condition, packet size transmissions will be, at the minimum, 2 Kbytes. Normally, after each successful packet transmission the packet size increases. It requires a full round trip delay (0.25 seconds over the satellite link) to acknowledge a successful packet transmission. In the case of our example after each successful transmission the packet size will increases in the following order: 4, 8, 10 12, 14 and 16 Kbytes. The throughput after seven roundtrips (1.75 sec) is (2+4+8+10+12+14+16) 66 Kbytes. This can be compared to the throughput during errorless periods of (7*16) 112 Kbytes.

As shown above the predominant problem with terrestrial TCP data delivery is the potential loss of packets due to network congestion and the subsequent discarding of packets along the data path due to overload. A complex combination of algorithms (slow start, congestion avoidance, fast-retransmit and fast recovery plus others) has been designed to regulate data entering the terrestrial network in order to minimize congestion. However, for GSO satellite networks the predominant problem with carrying TCP traffic is data loss due to transmission errors and latency due to travel time to/from the satellite.

Unfortunately the set of algorithms which regulate the data on terrestrial links to avoid congestion are sensitive to latency and data errors that in satellite networks result in confusion and network congestion. The effects cause reductions in the data rate when trying to avoid the perceived congestion as well as requiring additional retransmissions.

Because satellite transmission environments (predominantly rain effects) are well understood, satellite links have been made remarkably free of errors by using concatenated error correction methods commensurate with data interleaving and careful link design. However, satellite data errors introduced by new types of interference on a link with TCP traffic can create severe problems that are significantly out of proportion with the percentage of time that data is actually corrupted. This occurs for several reasons:

1. A TCP data packet may contain many Kbytes of data but is declared to be useless if it arrives with a single error or more after attempted error correction.
2. The loss of an entire packet must be signalled back to the sender requiring travel time and replacement time.
3. The loss of multiple data packets that is attributed to network congestion results in a decrease of attempted data rate by the sender, and
4. Data rate build-up in the link, or recovery after a loss of several packets is a function of how quickly data acknowledgements from the receiver are sent back. The satellite latency adds to the response time falsely indicating network congestion and limiting the speed of build-up of the data rate.

The effect of data packet losses in a satellite link has been shown relative to the resulting drop in data throughput rate [1]. An example given in the reference indicates that a five Mbyte data transfer on a 400 Kb/sec link with an actual data loss rate as low as 0.04% causes a 15% drop in throughput rate. Further, a loss rate of 1 % slashes the throughput by 81%. Thus the effect of intermittent data losses, although seemingly each of short duration and duty cycle, can cause considerably magnified losses in terms of Internet TCP data throughput.

Estimation of Sync Loss events due to rain

In the current GSO transmission environment sync loss generally is primarily caused by rain events. Rain fade events last on the order of minutes with median durations greater than 5 minutes. Furthermore, rain events are normally contained within worst case months and don't occur throughout the year. On the other hand, NGSO interference lasts on the order of seconds and may occur throughout the year at regular intervals.

Estimates of the number of sync loss events that GSO networks suffer per year from rain events are presented in order to determine a reasonable additional allocation for NGSO induced sync loss events. It is proposed to allocate a portion of those events to arrive at a value for x for the recommends 3.2 of ITU-R S.1323. In order to estimate the number of sync loss events per year the method described in reference [2] was adopted. This method assumes that durations longer than about 1 minute are log-normally distributed whereas shorter durations follow a power-law distribution. The model was tested against an extensive database of measurements made in the US, Europe and Japan. The measurements represented a wide range of climatic conditions and elevations.

In order to demonstrate the accuracy of the procedure the results were compared with fade duration measurements taken on the Olympus satellite network [3]. The results of the comparison are shown in Figure 1. The figure shows the number of fades (> 5 dB, 10 dB and 15 dB) per year exceeding the fade duration on the abscissa. For fades greater than 1 minute the analytic and measured curves are very close. There is some divergence for the very large fades greater than 15 dB. However, for 15 dB fades greater than 1 minute the predicted and measured number of events are within 100% of each other and the analytic curve is an upper bound. The most significant source of error in the model is the estimation of the median fade duration.

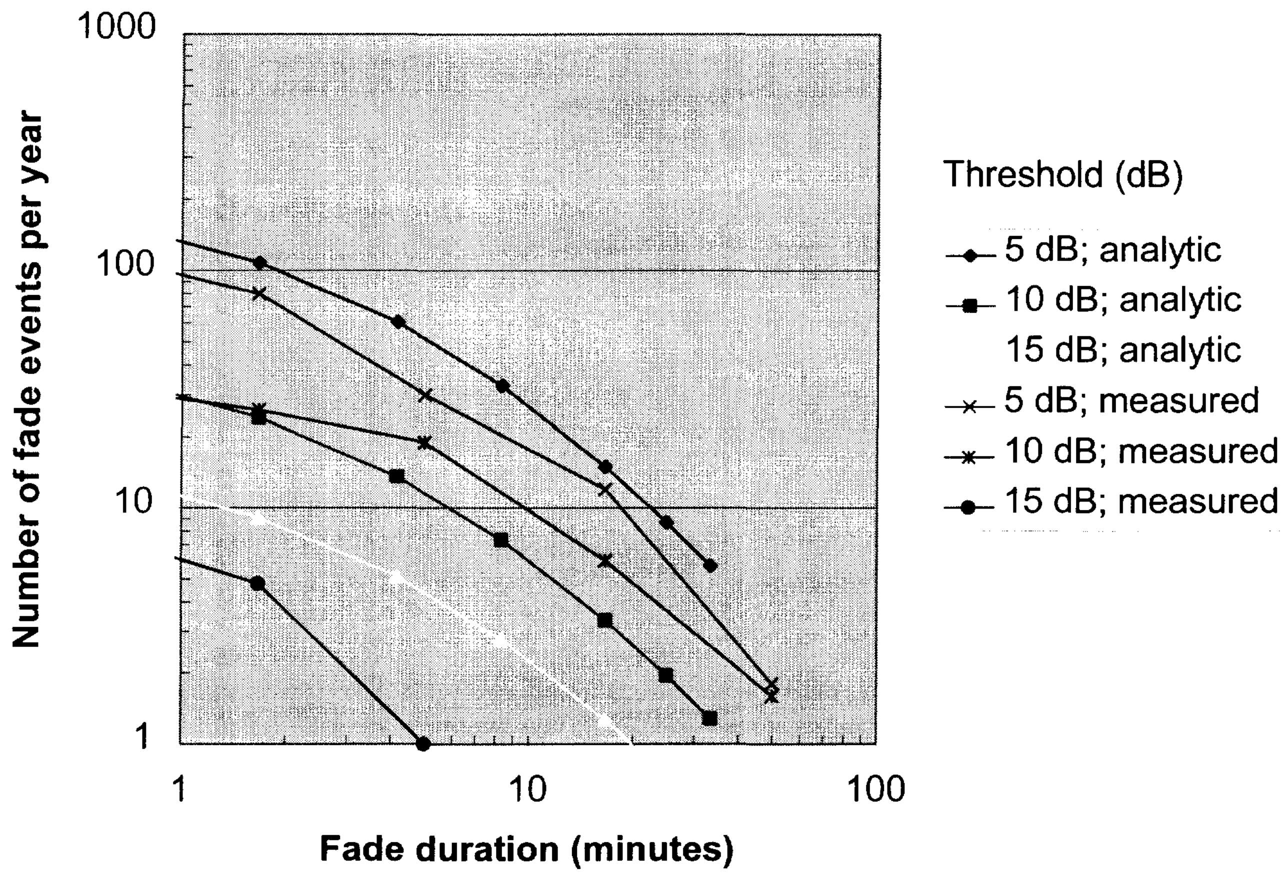

Figure 1: Number of fades (greater than a threshold) per year exceeding the durations on the abscissa

Results

Using the methodology in [2] the number of fades exceeding a level that would cause sync loss was calculated for several rain zones, link availabilities and earth station elevation angles. The analysis assumes that sufficient margin to meet the link availability is provided. A sync loss threshold 1 dB below the operational threshold was also assumed. A higher sync loss threshold would reduce the number of the calculated sync loss events.

NGSO interference, causing sync loss, is considered to be a significant problem for large GSO earth station antennas greater than about 3 meters. Links with larger size dishes typically have higher availabilities, in the order of 99.9%, especially in low rain zones.

Figure 2 presents the results of the analysis. Depending on the conditions, links experience between 3 and 57 sync. loss events per year from rain. Note that the U.S. has more than 50 % of its area in rain zones E and lower. Links in these areas experience less than 31 sync loss events per year.

Conclusions

In keeping with ITU traditions for new service introductions it would be reasonable to allow NGSO systems to cause an additional 10% increase in the number of sync loss events to the existing GSO service. Accordingly, the NGSO systems could be allowed to cause between 0 and 6 additional sync loss events per year to GSO networks occupying the band. Assuming that an average number of events (3) would be allowed, the value of x in recommends 3.2 of Recommendation ITU-RS.1323 should be greater than 120 days.

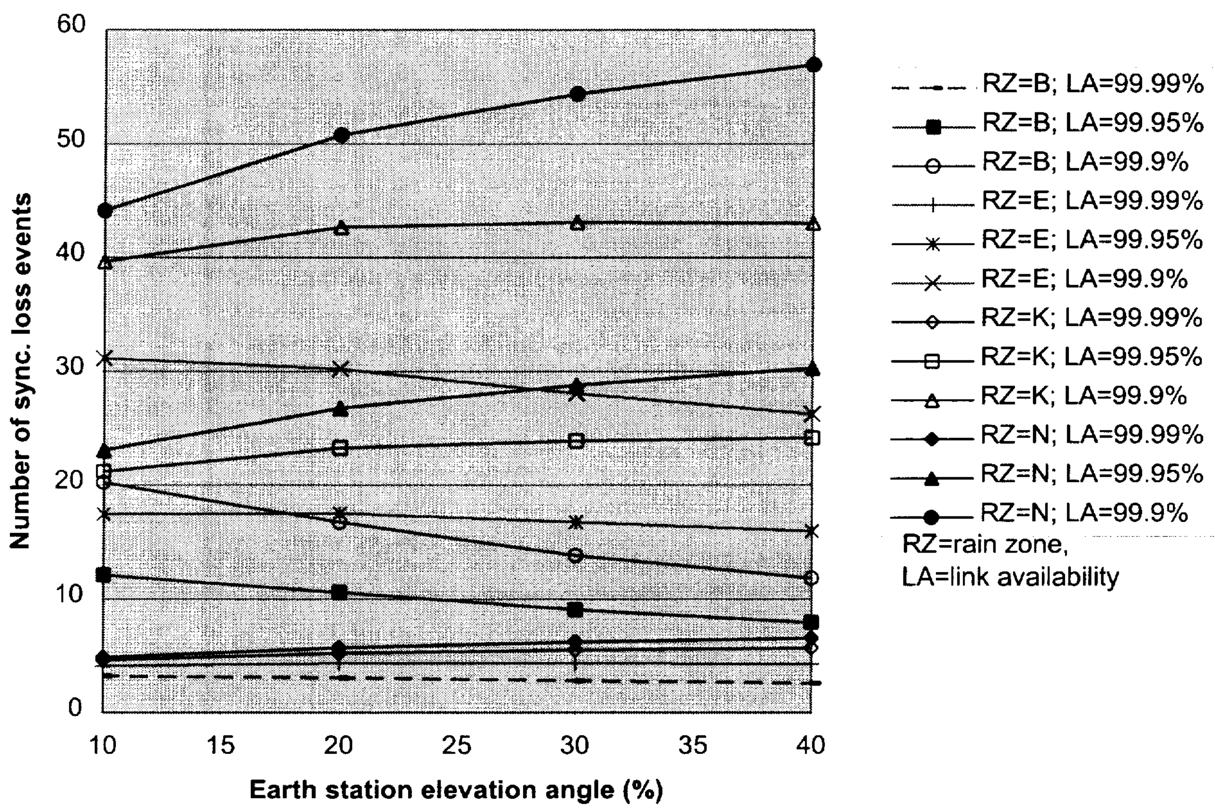

Figure 2: Number of sync loss events per year versus earth station elevation angle, rain zone and link availability

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